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REDUCTION OF CAVITATION ON SPILLWAYS BY INDUCED AIR ENTRAINMENT[1]

Discussion by H. CHANSON[2]

The writer would like to congratulate the authors for their extensive study on the difficult problems of cavitation damage and the use of aeration device. The writer wishes to discuss three specific points to complete the article : upper nappe entrainment, aerator submergence and velocity effects.

1. UPPER NAPPE ENTRAINMENT[3]

LOW (1986) and CHANSON (1988) performed air concentration and velocity measurements above an aeration device on a spillway model. In the aeration zone (figure 5, p. 363) their data clearly show that a large quantity of air is entrained through both the upper and lower free surface of the jet. More CHANSON (1989a) presented results obtained with identical upstream flow conditions and air inlets fully open (i.e. $P_N < 0.1$) or sealed (i.e. $P_N > 0.4$). These results indicate a substantial increase of the quantity of air entrained at the upper free surface when the pressure gradient increases

Indeed, from the end of the deflector the pressure gradient across the jet becomes negative and the rise velocity of air bubbles subject to such a negative pressure gradient becomes a fall velocity (CHANSON 1989a). This may explain the air entrainment process occurring at the upper surface of the jet.

CHANSON (1991) analyzed the diffusion equation of air bubbles at the free surface and developed an analytical solution for the upper nappe entrainment as :

[1-1] $$\beta^{up} = K_o * \left(\frac{l}{d} * \tan\psi^U - 2 * \beta^o * LN\left(1 + \frac{1}{2} * \frac{\tan\psi^U}{\beta^o} * \frac{l}{d}\right)\right) - 0.90 * \frac{l}{d} * \frac{u_r}{U_w} * \cos\alpha$$

where $K_o = \frac{1}{\sqrt{2 * \pi}} * e^{-0.5*(1.2817)^2}$,

β^{up} is the quantity of air entrained along the upper free surface, from the end of the deflector to the distance l, u_r is the rise velocity of air bubbles subject to negative pressure gradient P_N (CHANSON 1991), d and U_w the flow depth and velocity at the end of the deflector, and ψ^U is the lateral spread of the jet. CHANSON (1991) indicates that for low pressure gradient the angle of the jet spread may be estimated as ψ^U = 0.75

[1]Can. J. Civ. Eng., June 1991, Vol. 18 No.3, pp. 358-377, by James A. KELLS and C.D. SMITH.

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[3]Upper nappe entrainment refers to the free surface air entrainment at the upper nappe of a jet above an aeration device.

degree, but when the air inlets are sealed, the spread angle might be expected to be a function of the pressure gradient.

2. SUBMERGENCE[4] OF THE AERATION DEVICE

RUTSCHMANN and HAGER (1990) and CHANSON (1990) reported cases where the aerator could be drowned out, based on experimental data obtained by TAN (1984) and CHANSON (1988) on the Clyde dam spillway model.

For an aerator without a ramp RUTSCHMANN and HAGER (1990) suggested that the aerator becomes submerged for :

[2-1] $$\frac{t_s}{d} < 0.6$$

but a more extensive study by CHANSON (1990) indicates that the condition of aerator submergence is a function of the Froude number and the aerator geometry, and submergence occurs if the Froude number is less than a critical value :

[2-2] $$Fr < Fr^{sub}$$

where the submergence Froude number Fr^{sub} is a function of the aerator geometry. On a steep spillway α = 52.33 degree, with an aerator geometry including a ramp θ = 5.7 degree and an offset, CHANSON (1990) obtained :

[2-3] $$Fr^{sub} = 2.77 + 0.94 * \frac{d}{t_s}$$

for d/t_s in the range 2 to 4 (figure A1).

3. VELOCITY EFFECTS

For self-aerated flows WOOD (1983) re-analyzed STAUB and ANDERSON's (1958) data and showed that the friction factor for aerated flow f_e decreases when the quantity of air entrained increases. Such a result is confirmed by prototype data (JEVDJEVICH and LEVIN 1953; AIVAZYAN 1986) re-analyzed by the author, and the results are presented on the figure A2 as f_e/f versus the average air concentration C_e, f being the non-aerated friction factor.

Air concentration and velocity measurements, performed downstream of an aeration device on spillway model (CHANSON 1988), indicate an complete analogy between the flow downstream of an aeration device and self-aerated flows. Such a result suggests that the flow downstream of an aerator will be accelerated as the frictional resistance decreases with the air concentration (figure A2).

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[4]Under high subpressures the aeration device may be drowned out at low Froude numbers and this is called the submergence of the aerator.

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More, in the gradually varied flow region downstream of an aerator, CHANSON (1989b) developed a simple analysis based on the continuity equation for air and the energy equation that provides two simultaneous differential equations in terms of the mean air concentration and flow depth. These equations can be solved by numerical method and reproduce air entrainment on a spillway.

APPENDIX I.

The writer would like to correct an inaccurate reference provided by HOPPING and HOOPES (1988) and the authors : the reference SENG (1986) should be :

LOW, H.S. (1986). "Model Studies of Clyde Dam Spillway Aerators." *Research Report Ref. 86-6*, Univ. of Canterbury, New Zealand 1986.

APPENDIX II. REFERENCES

AIVAZYAN, O.M. (1986). "Stabilized Aeration on Chutes." *Gidrotekhnicheskoe Stroitel'stvo*, No. 12, pp. 33-40 (Hydrotechnical Construction, 1987, Plenum Publ., pp. 713-722).

CHANSON, H. (1988). "Study of Air Entrainment and Aeration Devices on Spillway Model." *Research Report 88-8*, Univ. of Canterbury, New Zealand.

CHANSON, H. (1990). "Study of Air Demand on Spillway Aerator." *Jl of Fluids Engrg.*, ASME, Vol. 112, Sept., pp. 343-350.

CHANSON, H. (1991). "Aeration of a free jet above a spillway. ", *Jl. of Hyd. Res.*, IAHR, Vol. 29, No. 5.

JEVDJEVICH, V., and LEVIN, L. (1953). "Entrainment of Air in flowing Water and Technical Problems connected with it." *Proc. of 5th IAHR Congress*, Minneapolis, USA, pp. 439-454.

LOW, H.S. (1986). "Model Studies of Clyde Dam Spillway Aerators." *Research Report Ref. 86-6*, Univ. of Canterbury, New Zealand..

RUTSCHMANN, P., and HAGER, W.H. (1990). "Air Entrainment by Spillway Aerators." *Jl of Hyd. Engrg.*, ASCE, Vol. 116, No. 6, pp. 765-762.

TAN, T.P. (1984). "Model Studies of Aerators on Spillways." *Research Report Ref. 84-6*, Univ. of Canterbury, New Zealand.

WOOD, I.R. (1983). "Uniform Region of Self-Aerated Flow." *Jl Hyd. Eng.*, ASCE, Vol. 109, No. 3, pp. 447-461.

APPENDIX III. NOTATION

C_e	mean air concentration of equilibrium uniform flow;
d'	equivalent clear water depth at the end of the deflector (m);
f	friction factor for non aerated flow;
f_e	friction factor for aerated flows;
l	distance along the spillway bottom from the end of the deflector (m);
P_N	pressure gradient number defined as : $P_N = \frac{\Delta P}{\rho_w * g * d'}$;

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u_r	rise bubble velocity (m/s);
U_w	flow velocity : $U_w = q_w/d'$;
Y_{10}	characteristic depth (m) where the air concentration is 10 %.
Y_{90}	characteristic depth (m) where the air concentration is 90 %.
β^o	air-water discharge ratio at the end of the deflector;
β^{up}	air-water discharge ratio at the upper free surface of the jet;
ψ	lateral spread angle of the jet computed between Y_{90} and Y_{10} : $\tan\psi = (Y_{90} - Y_{10})/l$;
ψ^U	lateral spread angle at the upper free surface of the jet.

Figure A1 - Submergence Froude number as a function of the flow depth

CHANSON (1991)

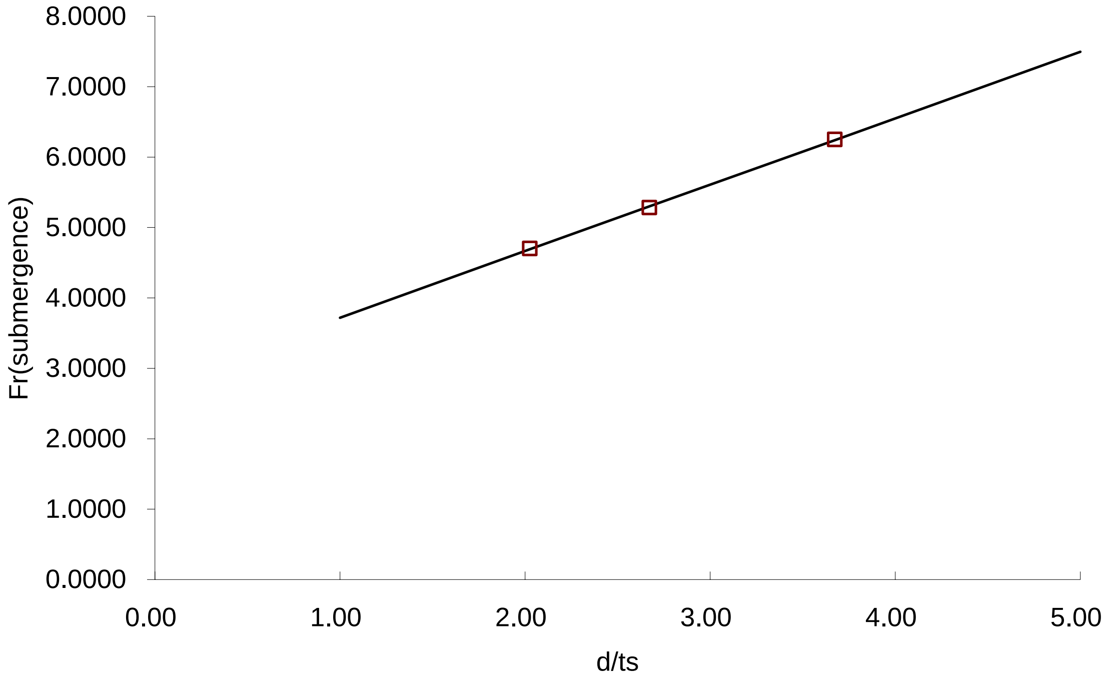

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Figure A2 - Ratio f_e/f as a function of the mean air concentration C_e

AIVAZYAN (1986) - JEVDJEVICH and LEVIN (1953)

STRAUB and ANDERSON (1958)